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BEHAVIOUR OF TENSILE TESTING OF X-120M STEEL FROM PLATE TO LINE PIPE DUE TO BAUSCHINGER EFFECT

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Behaviour of Tensile Testing of X -120M Steel from Plate to Line Pipe Due to Bauschinger Effect

Jai Dev Chandel [α] & Nand Lal Singh [σ]

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I. Introduction

Tensile properties of line pipe are one of the governing parameter as far as design of line pipe is concerned. The strength of line pipe steel is achieved by the lean and clean microalloying plus thermomechanical controlled processing and accelerated cooling (TMCP and AC) of steel plates. The line pipe manufacturing is involving the cold forming processes in whole cycle. During the cold forming of X-120M steel plate in first J-C-O process, strain energy stored in plates in terms of dislocations start releasing by movement, piling up against the barrier in the microstructure and cancellation of dislocations. The movement or cancellation of dislocations is known as bauschinger effect. The Bauschinger effect [1] refers to a property of materials where the material's stress/strain characteristics changed as a result of the microscopic stress distribution of the material. The Bauschinger effect is normally associated with conditions where the yield strength of a metal decreases when the direction of strain is changed. The basic mechanism for the Bauschinger effect is related to the dislocation structure in the cold worked metal. As deformation occurs, the dislocations will accumulate at barriers and produced dislocation pile-ups and tangles. It is fundamental that the bending [2] provides a heterogeneous deformation in section that determines the presence of high residual stresses. The wall thickness to diameter ratio t/D and strain hardening rate during cold expansion has the influence on the effect value. The general tendency is the softening growth in new higher strength steels that is stipulated by higher value of residual stresses. Nevertheless the value of the effect at equal strength is determined as well by the type of microstructure (specific value of each of the strengthening mechanisms resulted in strain hardening behaviour). The Bauschinger effect in TMCP steels has been previously studied [3] with respect to line pipe production by the UOE forming. The Bauschinger effect influences line pipe properties in two ways: during line pipe testing where tensile coupons of transverse direction to the line pipe axis need to be flattened prior to testing when comparing the line pipe and plate tensile properties. According to the API 5L standard, line pipe testing can be carried out by flattening of a line pipe wall-piece and tensile testing of the flattened part or by hydraulic expansion [4, 5] of a line pipe ring. During flattening the inner side of the line pipe wall is subjected to tension and outer side to compression, hence flattening adds a half cycle [6, 2] to the reverse deformation sequence already experienced by the line pipe material of high strength steel. Consequently a large difference in line pipe mechanical properties can be observed due to the method of testing (20% difference in the yield stress between flattened specimens and ring expansion. The difference in the test data also depends on steel chemistry. Recent investigations of TMCP steels have found that the Bauschinger effect depends on chemistry even for the same method of testing. At the moment, the Bauschinger effect dependence on the dislocation structure and microalloy particle distributions (related to a steel chemistry and processing parameters) is only known qualitatively and only a limited amount of data are available. With an increase in pre-strain the drop in yield strength of TMCP steels on reverse loading increases, due to an increase in dislocation density and

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consequent increase in number density of dislocation-particle interaction sites.

II. Materials And Experimental Methods

The experimental steel is a low carbon and low Pcm 'V-Nb-Ti-B' micro alloyed steel for studying the bauschinger effect on the tensile properties of line pipe steel. The chemical composition of experimental TMCP and ACC steel plate of grade API-5L, X-120M shown in table # 01. The parameters Pcm and CEQ are calculated as per formulae given as Pcm = C + Ni / 60 + Si / 30 + (Mn + Cu + Cr) / 20 + Mo/15 + V / 10 + 5B and CEQ = C + Mn/6 + (Cr+Mo+V)/5 + (Ni + Cu)/15.

Table 1 : Weight Percentage of Elements of X-120M Steel Plates

Element	**C**	**Si**	**Mn**	**P**	**S**	**Cr**	**Ni**	**Mo**	**Al**	**Cu**
Wt. (%)	0.065	0.290	1.950	0.012	0.005	0.170	0.040	0.130	0.042	0.021
Element	**Ti**	**V**	**Nb**	**Ca**	**N**	**B**	**Al/N**	**Nb+V+Ti**	**Pcm**	**CE**
Wt. (%)	0.012	0.001	0.042	0.001	0.002	0.004	21	0.055	0.211	0.454

The TMCP and AC X-120M steel plate has been converted into line pipe through J-C-O-E technique [7] as shown in the figure # 01. The complete detail of J-C-O-E line pipe manufacturing/forming has been given in the reference number [7] by the authors titled "Formation of X-120M line pipe through J-C-O-E Technique, J D Chandel, and N L Singh. Journal of Scientific Research Publication, Engineering, USA, Volume # 03, No. 04 April-2011, Page # 400-410" and the tensile test samples has been cut as per API-5L at every stage of the formation. Tensile test has been performed on the experimental plate in the longitudinal as well as in the transverse direction to the rolling direction. Similarly the tensile test has also been performed on the experimental formed line pipe of above steel to longitudinal as well as in transverse direction to the axis of the line pipe.

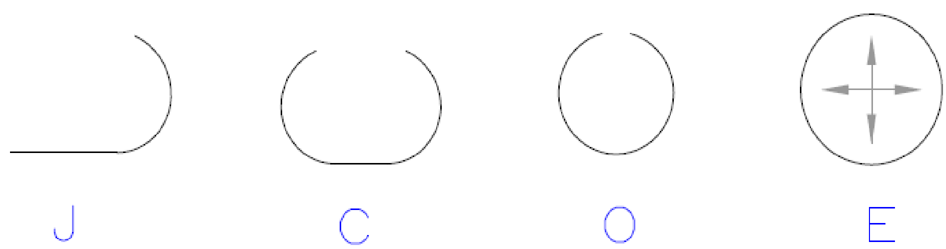

Figure 1 : Schematic of J-C-O-E Process.

III. Results And Discussions

The experimental TMCP and AC steel having lath-type and bainitic-type ferrite with high dislocation density as shown in figure # 02 in TEM microstructure and the line pipe formed from the experimental steel plate shown as in figure # 03.

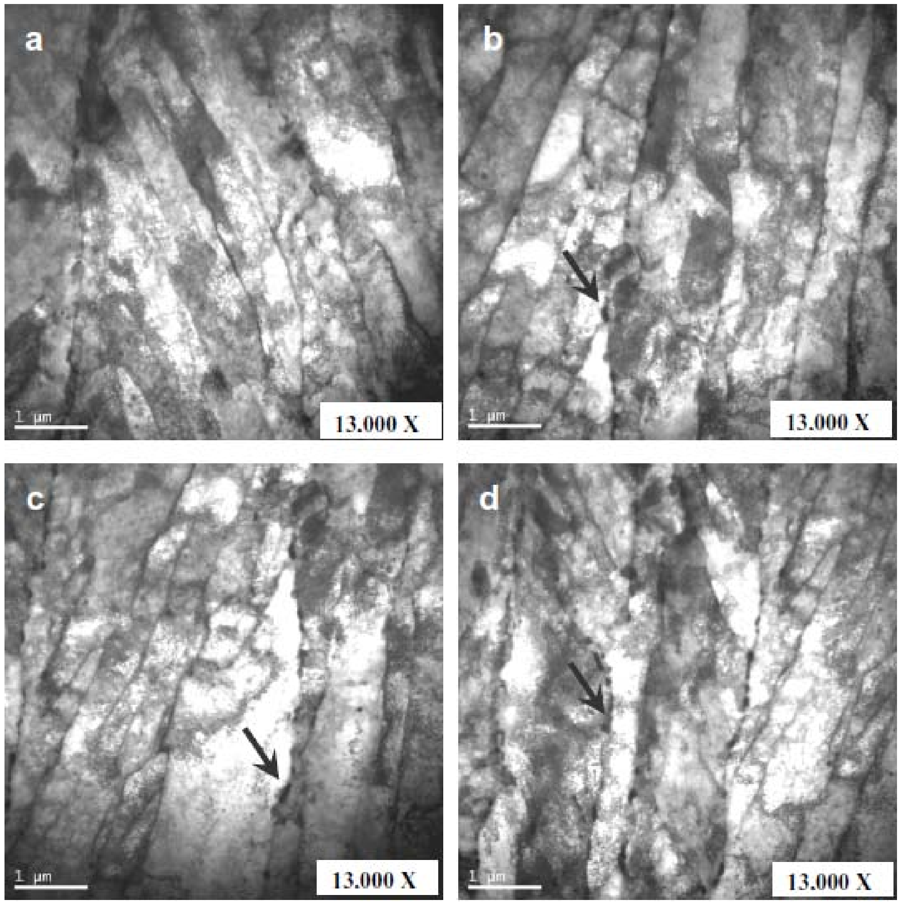

Figure 2 : Bright field TEM micrographs showing lath-type and bainitic-type ferrite with high dislocation density. Inter-lath carbides are indicated with arrows.

Figure 3 : Experimental X-120M Plate and Mechanically Expanded Line Pipe

The tensile testing has been carried out on experimental steel plate and line pipe for UTS, YS and YS/UTS ratio. The samples have been cut for above parameters as per API-5L at various stages of line pipe manufacturing namely before forming (from plate), before mechanical expansion (after line pipe forming) and after mechanical expansion during the line pipe manufacturing cycle. The results of above parameters are shown in figures # 04-09.

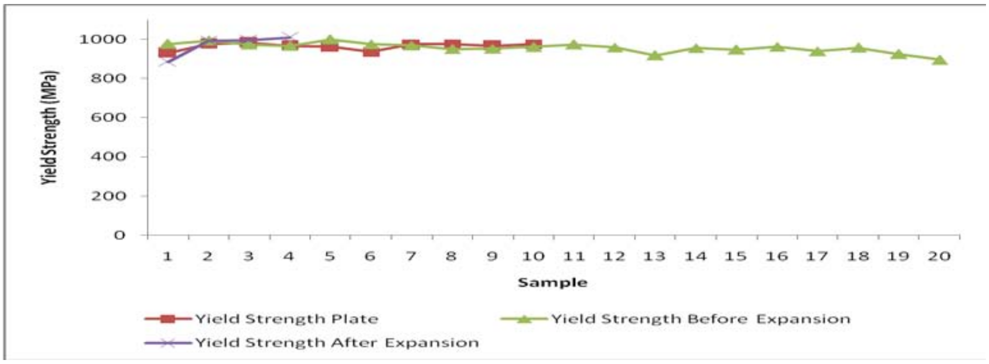

Figure 4 : Yield Strength in Longitudinal Direction of X-120M

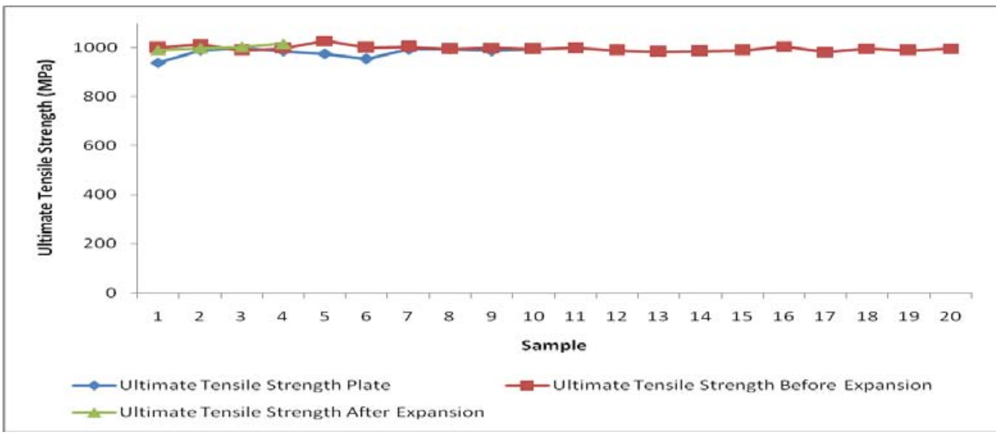

Figure 5 : Ultimate Tensile Properties in Longitudinal Direction of X-120M

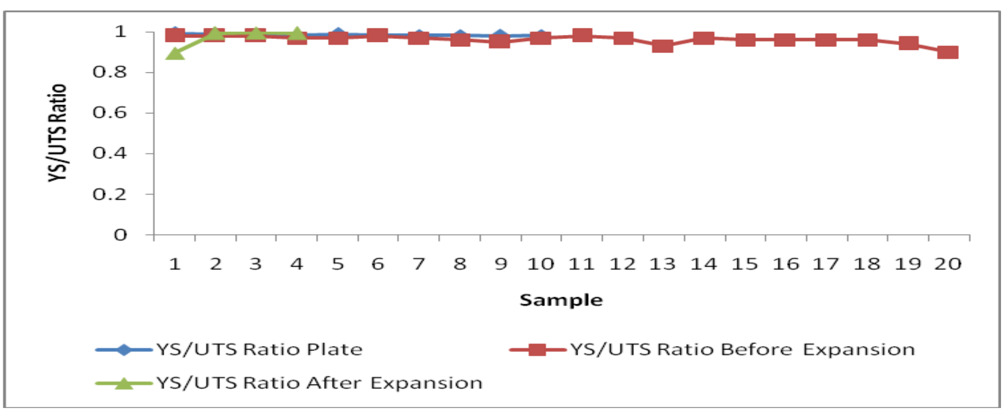

Figure 6 : YS/UTS Ratio in Longitudinal Direction of X-120M

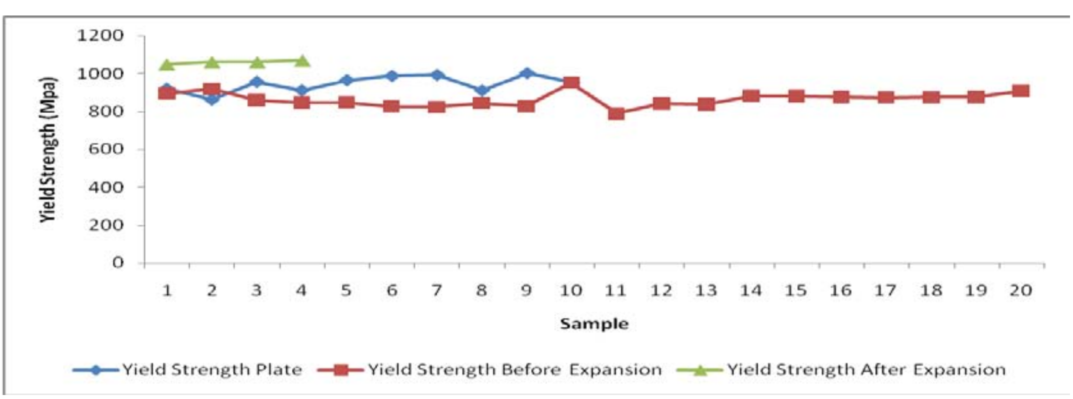

Figure 7 : Yield Strength in Transverse Direction of X-120M

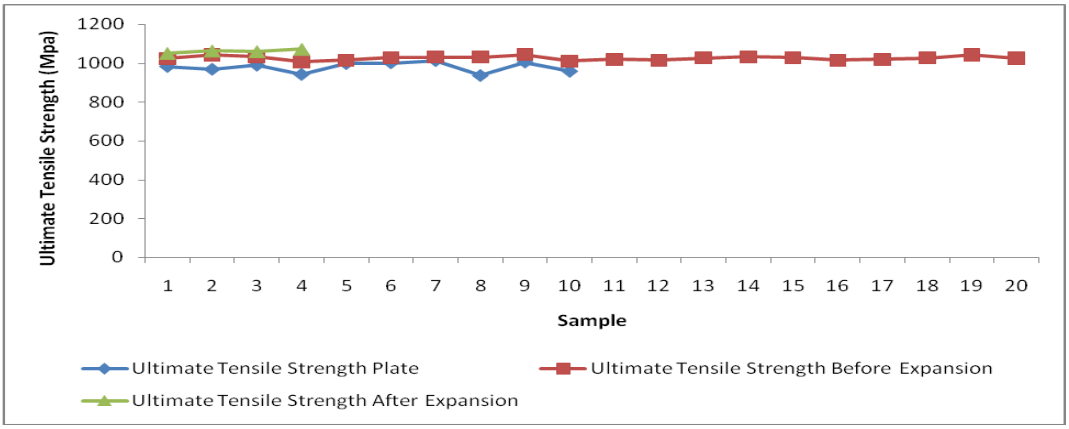

Figure 8 : Ultimate Tensile Properties in Transverse Direction of X-120M

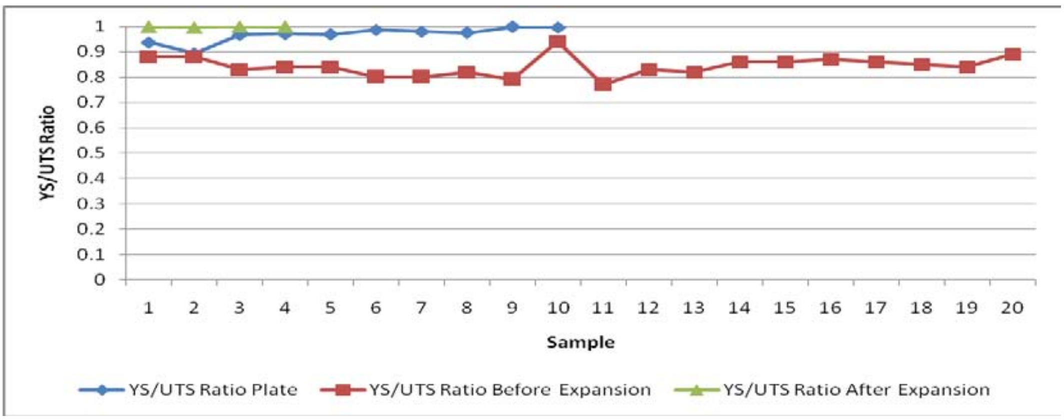

Figure 9 : YS/UTS Ratio in Transverse Direction of X-120M

Recent studies of plate to line pipe tensile properties changes have shown an increase in both YS and UTS from plate to line pipe due to work-hardening. In longitudinal direction the reverse deformation as a source of work-softening is considered less prominent form plate to line pipe. In transverse direction a decrease in the YS and YS/UTS ratio from plate to line pipe forming and increase in YS and YS/UTS ratio after mechanical expansion was observed. The YS, UTS and YS/UTS ratio remain almost same from plate to final cold expanded line pipe along the rolling direction as shown in figure # 04-06. In case of transverse to the rolling direction the yield strength after cold J-C-O-E formation decreases as compared to the plate. After cold mechanical expansion the yield strength increases as compared the plate as shown in figure # 07. The strength is achieved mainly by TMCP and AC process. During TMCP and AC process dislocations are generated and the desired microstructure has been obtained by accelerated cooling which ultimately leads to the required strength level. During the first cold forming operation the dislocations start moving and as a result generation of opposite sign dislocations, this leads to drop in yield strength. In figure # 08 the ultimate tensile strength increases marginally after both the cold forming operations. In figure # 09 the YS/UTS ratio follow the same pattern as of YS as YS/UTS ratio parameter depends on YS. On the basis of these data and some earlier work [2, 8] for line pipe X-70M and X-65M respectively, it is possible to conclude, that, during line pipe forming, two competitive processes take place in the line pipe material at the same time, work hardening due to the unidirectional straining and work softening due to the reverse cold deformation (the Bauschinger effect). During plate to line pipe cold forming the strain levels and deformation direction add to the dislocation structure formation.

IV. Conclusion

Following conclusion can be drawn from the present experimental study.

1. The values of the parameters of YS and YS/UTS drops after forming in transverse to the rolling direction of the TMCP and AC plate with respect to the values of the parameters of before forming stage and in longitudinal direction the values of the above parameters more or less remain the same.
2. The values of the parameters of YS and YS/UTS increases after mechanical expansion in transverse to the rolling direction of the TMCP and AC plate and in longitudinal direction the values of the above parameters more or less remain the same.

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